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THE PHYSIOGRAPHY OF THE BISHOP CONGLOMERATE, SOUTHWESTERN WYOMING[1]

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Introduction.—The purpose of this paper is the description of a series of peculiar, gravel-capped plateaus in the southwestern part of Wyoming, and an attempt to decipher, in so far as the evidence will permit, the physiographic history of the region both before and after the deposition of the gravels. It will be shown that a study of the physiography leads to some interesting and suggestive conclusions as to past changes in the geography of the region described, which on the whole agree remarkably well in broader features with certain conclusions which have been reached from other lines of approach.

Geologists are recently beginning to recognize more clearly than ever before the importance of climatic conditions in determining the nature of the geologic processes at any given time, and in determining the nature of the deposits formed as a result of these processes.[2] At the same time they are beginning to reason back from the character of a deposit to the causes which are responsible for its distinctive features; to the climatic and other conditions under which the deposit was made. It is one of the purposes of this paper to call particular attention to this line of study by attempting to show from physiographic evidences that there have been in comparatively recent geological times a series of marked climatic changes affecting the region under discussion.

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[1] Published by permission of the Director of the U.S. Geological Survey. The writer is indebted to Dr. Alfred R. Schultz for information in regard to conditions on Little Mountain, for certain of the accompanying photographs, and for helpful discussions in field and office; also to Professor A. C. Gill for a reading and criticism of the manuscript.

[2] Joseph Barrell, "Climate and Terrestrial Deposits," *Jour. of Geol.*, XVI; Ellsworth Huntington, "The Glacial Period in Non-glaciated Regions," *Bull. Geol. Soc. Am.*, XVIII, 351–88; Chamberlin and Salisbury, *Text Book of Geology*. III, 305–7, 452–53.

The paper, aside from its descriptive part, is an inductive and deductive study carried out with the idea of reconstructing the past history of the region from the physiographic features still remaining.

There is in the southwestern part of Wyoming a belt of plateau country skirting along the northern base of the Uinta Mountains in an east-and-west direction parallel to the range. This has a general slope to the north away from the mountains. During the summer of 1908 a portion of the plateau lying north of the eastern end of the range and north and east of Green River was mapped in detail by a United States Geological Survey party. The conditions observed in that portion of the area form the basis of this paper. Fig. 1 is a sketch map of parts of southwestern

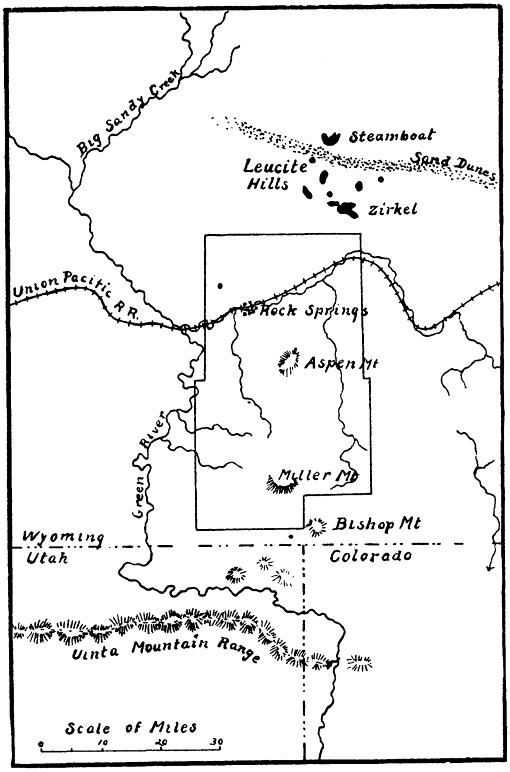

FIG. 1.—Sketch map of portions of Wyoming, Utah, and Colorado, showing the general location of the features described in this paper.

Wyoming, Utah, and Colorado which will indicate the general location of the region and its relation to the near-by important physiographic and geographic features. Fig. 2 is a more detailed map of a portion of the area outlined in Fig. 1 and shows all the various topographic, hydrographic, and cultural features referred to in the following discussion.

Referring now to the detailed map it will be noted that the entire area is drained by tributaries of Green River. Bitter Creek, one of the largest of these entering from the east, drains all but the extreme southern and western part. Red Creek takes the waters of the southern part directly south to Green River, and Sage Creek, flowing northwest, carries the drainage of the western part directly to the river.

The climate is semi-arid, with an average rainfall of from ten to fifteen inches per year. The topography is typically that of a semi-arid region of moderate relief; low areas, corresponding to belts of soft rock, are followed by steep scarps with dip slopes. Each zone of harder rocks is represented by a more or less pronounced scarp, depending on the resistance, thickness, and dip of the component layers. One of these scarps formed by a series of heavy-bedded sandstones is over 1,000 feet in height.

The plateau.—The most conspicuous feature of the topography within the area of the detailed map is a high, even-topped plateau lying at an elevation of from 1,000 to 1,500 feet above the bottoms of the major stream valleys. This is everywhere capped by a gravel-deposit partly consolidated at the base into a resistant conglomerate which, on account of its resistance to erosion, is responsible for the preservation of the plateau while the surrounding country was worn down. From its northern extremity at the northwestern base of Aspen Mountain the plateau extends southward for a distance of fourteen miles to Miller Mountain where it ends abruptly in a steep scarp facing southward to the basin of Red Creek. The plateau varies in width from less than a mile to eight or ten miles. The largest remnant extends southward from Aspen Mountain to Miller Mountain as indicated, but there is a long arm running northwest from Miller Mountain between the valleys of Sage and Little Bitter creeks for a distance

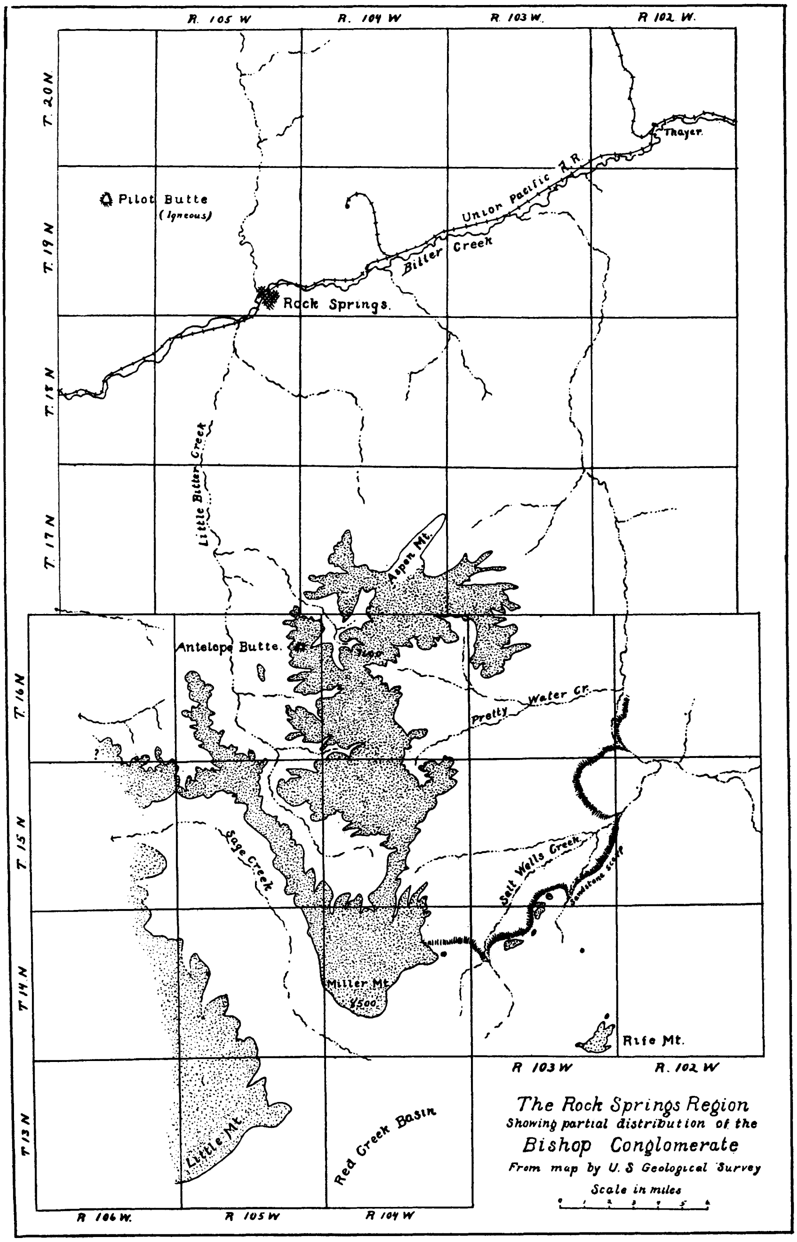

FIG. 2.—Map of the Rock Springs region

of fifteen miles or more, nearly to Green River. A similar plateau, known as Little Mountain (Quien Hornet Mountain of the Powell Survey), lies to the west and southwest of Miller Mountain, from which it is separated by the deep valley of Sage Creek. Rife Mountain, a flat-topped mesa about two miles long by one mile broad lying nine miles east of Miller Mountain, is a detached remnant of the same plateau lying at an accordant altitude and capped by similar gravels. Between this and Miller Mountain are five smaller isolated gravel-capped areas lying at accordant altitudes. Ten miles southeast of Miller Mountain is a good-sized remnant of the same gravel-capped plateau known as Bishop Mountain, or sometimes locally as Pine Mountain. It is from this plateau that the gravel-formation, the Bishop Conglomerate, receives its name.

Bishop Mountain is the type locality of Powell's "Bishop Mountain Conglomerate" as defined in his Uinta Mountain report. The shorter term, "Bishop Conglomerate,"[1] has however recently been adopted by the Board of Geologic Names, and is, therefore, used here in preference to Powell's name. The Bishop Conglomerate is the same as the "Wyoming Conglomerate" of this same region as described by King in his "Survey of the 40th Parallel."

The surface of the plateau is everywhere even and the isolated portions all lie at accordant altitudes. The surface as a whole strikes about 20° north of west and slopes to the north from the most southern exposure to the low area four miles south of Aspen Mountain. There is then a rise toward the north to the base of the mountain. A few elevations will give an idea of the slope of this surface. The highest part of Miller Mountain is, in round numbers, 8,500 feet; Rife Mountain, 8,400 feet; the low area south of Aspen, 7,600; and the plateau at the west base of Aspen, 7,900 feet. Bishop Mountain is considerably higher and the same is true of the southern part of Little Mountain. The slope of the gravel surface is so even, and the accordance in elevation of isolated remnants is so close, that one may stand on the top of one of them and, looking along the strike, see the trees on the top of the others, even when the distance is six or eight miles. No suggestion of the intervening valleys then appears. This close accordance indicates that all the gravel-capped areas once formed parts of the same even plateau-surface and have been separated only by subsequent erosion. The plateau is still in the process of active dissection. Adjacent parts are in many cases separated by valleys over 1,000 feet deep whose tributaries, by working their way back into the plateau by head-water erosion, are responsible for the very irregular ground-plan of the parts still remaining. Fig. 3 gives a good idea of the sky-line of the plateau as seen from a distance of about four miles.

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[1] A. R. Schultz, "The Southern Part of the Rock Springs Coal Field, Sweetwater Co., Wyo.," *Bull. U.S.G.S. No. 381*, 112.

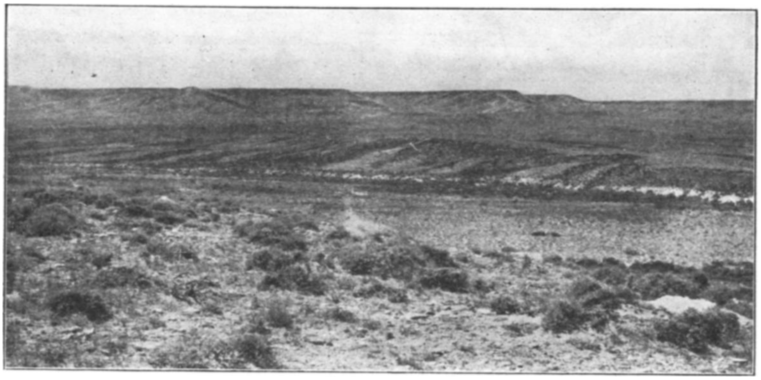

FIG. 3.—Miller Mountain plateau as seen from a distance of four and one-half miles, looking west from the banks of Salt Wells Creek. Note the even sky-line. The view shows the edge of the plateau for a distance of five miles without disclosing any visible irregularity. The conglomerate capping here averages between fifty and one hundred feet in thickness and is well cemented at the base. The top of the plateau is about 1,000 feet higher than the stream in the foreground. Between the stream and the base of the scarps the wash-apron described on a later page is fairly well shown.

Character of the rock floor of the plateau.—As already stated, the entire plateau is capped by gravels which may be loose and unconsolidated in the upper part but are as a rule firmly cemented at the base. This conglomerate capping varies in thickness from eight to ten feet to as much as two hundred feet in different parts of the area. The rock-surface on which it lies is a very even, beveled rock floor which, though it may be slightly irregular in places, is on the whole remarkably smooth. In no part of the area studied were noticeable irregularities in the surface evident in the exposed line of contact with the underlying rocks. In several places, but best along the eastern face of Little Mountain, this contact can be seen continuously for several miles, and in all that distance does not display any appreciable irregularity. The probable reason for this great regularity is that the underlying rocks are uniform in texture and quite soft. In localities where the underlying rocks are markedly unequal in hardness the contact is slightly irregular in detail, but still regular in general.

A large part of the gravel-capped plateau lies on the truncated crest of the Rock Springs dome, a broad anticline of sedimentary rocks about ninety miles in length with the long axis running a little west of north through Aspen Mountain. This anticline has a total width of about forty miles. In the southern part of the area the plateau truncates the tilted rocks on the northern flank of the Uinta uplift. The beveling of the underlying rocks by the plateau-surface is very marked. In certain parts of the Rock Springs dome these underlying rocks dip in both directions from the crest, sometimes at an angle as high as 35°, yet the plateau-surface cuts evenly across them entirely irrespective of structure and almost irrespective of hardness (Fig. 4). Faults and folds in the underlying rocks have no expression in the plateau-surface.

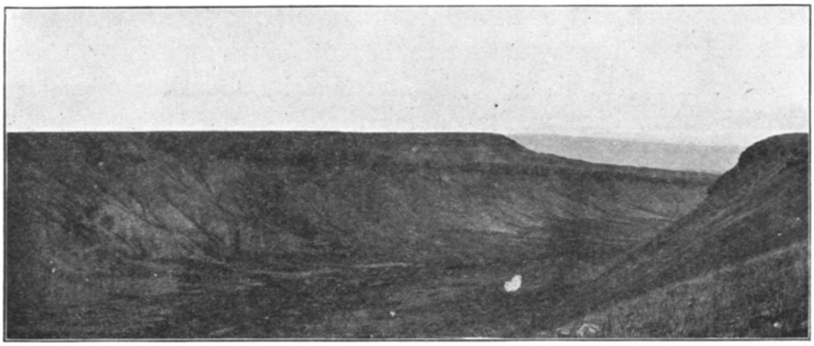

FIG. 4.—Unconformity of Bishop Conglomerate with underlying Cretaceous rocks southeast of Aspen Mountain. The dark horizontal bed at the top is the conglomerate. Note how evenly the base of this conglomerate truncates the dipping sandstones beneath. This is typical of conditions all along the edge of the plateau.

The rock floor of this plateau is clearly a peneplained surface of very considerable extent and great regularity. We are not dealing in this case with an imaginary peneplain whose existence is deduced from the finding of hilltops at about the same level, but with one in which the original planed surface is still preserved over a broad area with its edges exposed and with an evenness the more striking on account of the folded condition of the underlying rocks.

Extent of the peneplain.—The portion of the area mapped in detail in the summer of 1908 in which remnants of the peneplain occur measures about twenty-seven miles from north to south and twenty-two miles from east to west. Including Bishop Mountain and the western part of Little Mountain which were not mapped in detail, but which are without doubt parts of the same peneplain, the dimensions just given will be increased by about ten miles in either direction. This makes an area of at least 1,200 square miles which we can definitely say was reduced to the condition of a peneplain of very slight relief.

There is good evidence that the peneplain had a much greater extent than that indicated by the area over which portions of the gravel-capped plateau still remain; for the lava-sheets of the Leucite Hills, which are scattered over a considerable area from fifteen to forty miles north of Aspen Mountain, lie on the beveled surfaces of the underlying sedimentary rocks. The lava-flows have preserved these beveled surfaces at their original elevations. These, in the case of the larger flows, are so nearly in accord, and so nearly agree with those of the gravel-capped plateaus to the south of Aspen Mountain, that it is reasonably safe to assume that the lavas were poured out on the surface of the same peneplain. The following figures will illustrate this relationship: Approximate elevation of the base of the gravels south of Aspen Mountain, 7,600 feet; base of Pilot Butte lava-flow, 7,900 feet; Zirkel Mesa, 7,600 feet; Steamboat Mountain, forty miles north of Aspen, 8,250 feet; and North Table Mountain, about 8,150 feet. All of these agree in that they, like the plateau to the south, stand from 800 to 1,200 feet above the level of the adjacent valleys. Several of the smaller lava-flows are at lower levels and do not agree closely with those mentioned above. A small flow three miles northwest of Zirkel Mesa has an elevation of 7,900 feet, 300 feet higher than that of Zirkel. Most of the flows which are discordant are smaller and lower than the average and evidently were poured out after the principal period of extrusion on a surface somewhat reduced by erosion. The larger of the Leucite Hills lava-flows do not differ more among themselves as to elevation than do different parts of the Miller Mountain plateau itself.

Monadnocks.—Aspen Mountain which rises about 1,000 feet above the level of the plateau to the south is a ridge of resistant quartzite formed by the impregnation with silica of a soft Cretaceous sandstone. On account of its superior hardness it stands as a monadnock on the peneplain. From the summit of the mountain there is on the north a steep drop to the lowlands of Bitter Creek, and to the south a gradual slope to the surface of the gravel plateau. At the time of planation Aspen was reduced to a moderate slope. The present steep slope on the north side of the mountain is the result of more recent erosion.

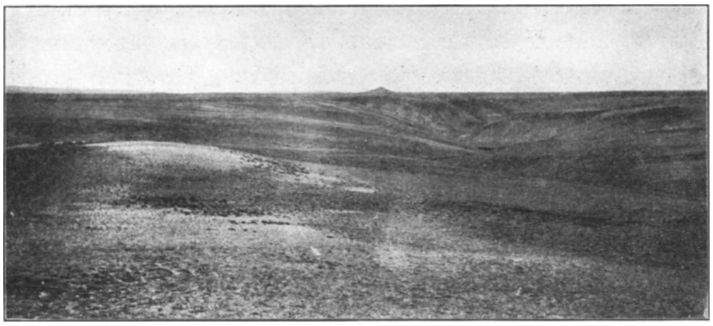

FIG. 5.—Antelope Butte, a monadnock on the peneplain southwest of Aspen Mountain as seen from a distance of three and one-half miles. To the right in the middle distance is the head of a stream-valley which is working back into the plateau. This view gives a fair idea of the appearance of the surface of the plateau, though it is here somewhat less even than usual on account of proximity to the invading stream-valley. In the immediate foreground is a smaller monadnock similar to Antelope Butte. (Photo. by A. R. Schultz.)

Six miles southwest of Aspen is a much smaller monadnock known as Antelope Butte which rises as a conical hill about 150 feet above the surface of the peneplain. Fig. 5, a view taken from another small monadnock near the base of Aspen, shows well its character and relation to the surface of the gravels. This, like Aspen, is due to the silicification of a Cretaceous sandstone. Near by there are several other smaller masses of silicified sandstone projecting through the gravels which in this vicinity are comparatively thin, sometimes not more than ten or twelve feet in thickness.

Character and origin of the gravels.—The conglomeratic capping of the plateau is made up for the most part of gravel and sand of greatly varying texture. In the low area south of Aspen Mountain the pebbles are not as a rule more than from one-half to one inch in diameter, and the greater part of the material on the surface is a fine gravel or sandy loam derived from the disintegration of the conglomerate. As one goes south the material gradually becomes coarser till, at the southern end of Miller Mountain, bowlders varying from one to five feet or more in diameter are common. On the south slope of the mountain many large bowlders strew the surface to such an extent that passage with a horse is difficult. From the low area *northward* to Aspen Mountain the material also becomes coarser. In some of the deep gullies cut into this deposit one may find many bowlders like those shown in the photograph, Fig. 6. Diameters of four or five feet are not uncommon in this part of the deposit. The bowlders are subangular for the most part, like those shown in the photograph. They occur imbedded irregularly in finer gravels and sand.

The gravels are rudely stratified, but in ordinary exposures the stratification cannot be seen well. At first the deposit at the base of Aspen was thought to be of glacial origin on account of the large size of the bowlders, their subangular nature, and their occurrence scattered irregularly through the finer gravels. Later this idea was abandoned on account of the complete absence of striations on any of the bowlders, the lack of any signs of glacial action on the bed-rock underneath, and finally on account of the local nature of any possible supply ground. Aspen Mountain from which the material came is too small to have supported glaciers under any circumstances.

South of the low area the gravels consist largely of red and white quartzites with occasional specimens of gneiss, schist, diabase, and limestone. There can be no doubt as to their origin in the Uinta Mountains to the south where similar rocks are found.

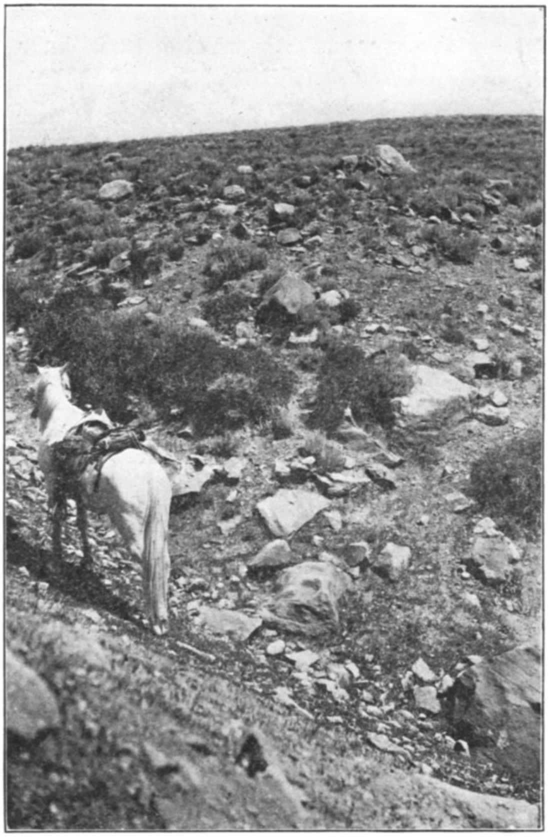

FIG. 6.—Bowlders exposed in a stream-gulley in the Bishop Conglomerate on the southeast flank of Aspen Mountain, well down on the plateau. This is a typical example of the coarser débris which has accumulated round the base of the mountain. It is of local origin, entirely distinct from the Uinta gravels to the south.

This origin is also amply indicated by the fact that the material becomes coarser toward the mountains. North of the low area, round the base of Aspen, the gravel is of local nature, derived from the sandstones and quartzites of the mountain. The surface here slopes to the south in a direction opposite to that of the portion covered by the Uinta gravels.

The low area referred to is evidently fundamentally of a constructional nature lying at the junction of two fans, the one from the Uinta Mountains, the other from Aspen. Where these fans meet there is a distinct interfingering of the two kinds of gravel. In riding along in an east-and-west direction one is first on Uinta gravels, then on those from Aspen. Areas of one extend out into areas of the other. The vertical interlapping of the two was nowhere seen, though it undoubtedly exists. The whole relation of the two indicates that they were spread out at the same time the one from the Uintas, the other from Aspen Mountain.

INTERPRETATION

Planation.—From the relations just described it is evident that the Rock Springs region has been subjected to a long period of planation during which the surface of the land was reduced to the condition of a peneplain. The rocks were worn down until differences in structure produced no corresponding effect in the topography of the plain. In a few exceptional cases, like those of Aspen Mountain and Antelope Butte, hard rocks remained above the plain as monadnocks. That the plain was of considerable extent is shown by the fact that it covered not only the area south of Rock Springs as far as the Uinta Mountains, but also, as is indicated by the relation of the lava-flows of the Leucite Hills, all the area between the Uintas and the Wind River Mountains 200 miles to the north. Its limits are unknown.

Present differences in elevations of portions of the peneplained surface still remaining indicate that the whole region was reduced to the condition of a gently undulating plain of advanced old age with a relief of 700 to 800 feet in distances of 25 or 30 miles. This conception corresponds well with the observed great regularity of the plain surface in details and its broad irregularity when distances of 25 or 30 miles are considered.

As to the time of planation it is not possible with the information at hand to make any definite statement further than that it was later than the Green River Eocene. There can be no question of this for along the eastern face of Little Mountain the peneplain truncates rocks of this age. From long-distance observations west of Green River it is thought that the planed surface will be found to truncate rocks of the Bridger formation along the southern rim of the Bridger basin. Gravel-covered, planed surfaces which may have originated at the same time as those of the Rock Springs region are reported by Woodruff[1] from the Wind River basin of Wyoming. The evidence there indicates that the planation was not completed until after the deposition of the White River Oligocene. The fossils in the gravels do not definitely determine the age, but the beds lie above various formations from Colorado up through and including Mesaverde, Cretaceous, and Wind River Eocene, younger than Fort Union. They were not seen in contact with White River beds, but deformations which moved the Wind River beds as well as the White River Oligocene, overlying, occurred previous to the deposition of these gravels, hence the inference that they are younger than White River. If these planed surfaces in the Wind River basin are the result of the same period of planation as those of the Rock Springs region, then the date of this is established with little question as later than White River Oligocene.

In the absence of more definite evidence from the area under discussion we can only assert that the planation took place in the late Tertiary, and that it was doubtless in late Tertiary time that the culmination of the base-leveling process was reached. Further observations in other regions or more extended observations in this region may later make it possible to assign a more definite date for the planation.

For the present discussion we will assume that planation was in progress during the latter part of the Tertiary, and that it ceased with the beginning of the crustal movements which occurred between the Miocene and the Pliocene; the reader meanwhile bearing in mind that this date is merely provisional pending the discovery of more exact data.

Climatic conditions at the time of planation.—Planation over large areas may be accomplished by any one of three agencies: marine planation, subaërial denudation under conditions of moist climate, or denudation under arid conditions by wind scour. In the case at hand the first of these, marine planation, is thrown out of the question by the broad irregularities of the peneplain and its gently undulating nature, as well as by the improbability of such planation having occurred so far inland in late Tertiary times.

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[1] E. G. Woodruff, unpublished data. See U.S. Geological Survey bulletin on the "Coal Beds of the Wind River Basin, Wyoming," soon to be published.

The second explanation, normal peneplanation under a moist climate, accords well with the facts. We find a smooth, yet gently undulating surface with differences in relief amounting to 700 or 800 feet at points twenty-five miles or more apart. This indicates slopes of from ten to thirty feet per mile. These conditions are what should be expected if the peneplain is the result of normal denudation under moist conditions.

In the third place there is the possibility of planation under arid conditions by wind scour. This agency in an arid climate is worthy of serious consideration, for, under favorable conditions, it seems capable of playing a very important rôle in denudation. Passarge has shown that under conditions of long-continued aridity in an inclosed basin remarkably even plains may be developed over large areas by this agency combined with the action of occasional rains, which by washing loose material into the hollows tend to counteract any tendency on the part of the wind toward the formation of basins in the areas of the more easily eroded rocks. Plains of such an origin with harder rock-masses standing above them as "Inselberge" are described from South Africa. In so far as the smooth plain condition and the occurrence of monadnocks projecting above it is concerned the conditions observed in the Rock Springs region agree with the wind-erosion hypothesis. Another condition which is in harmony with this interpretation is that the rock floor of the peneplain underneath the gravels, wherever observed, was found to be fresh and undecayed. There was no evidence of an old soil underlying the gravels such as might be expected if the planation were performed under moist conditions. It is possible however that any old soils which may have been formed were removed during an arid period just preceding the deposition of the gravels.

While the features of the peneplain may be interpreted as due to wind erosion, the writer is inclined to favor the hypothesis of subaërial denudation under moist conditions. The reasons for this preference are as follows: (1) Present conditions in the region indicate only a moderate efficiency of wind erosion. The region at the present time is subjected to desert conditions, though these are not now extreme. The winds are strong and blow almost continually, especially during the day. Wind action is conspicuous in places where conditions are particularly favorable, and a very considerable amount of material is removed in this way, yet the present features of topography are due rather to stream work than to the wind. In places where the streams by cutting have exposed softer rocks and these are of such a nature as to be easily eroded, wind scour is noticeable, but otherwise not. Practically all the details of topography are the result of water action. In southern California where the average rainfall is less than five inches per year the topography is almost entirely the result of stream action. There is even less evidence of wind work than in Wyoming. All the dissection of the mountains is of the type produced by streams and there is little sign of wind erosion. It is true that the winds do pick up and carry away considerable dust at certain times, particularly during dust storms, but their topographic effect as compared with that of desert streams is almost negligible. For these reasons the formation, by wind erosion, of a smooth peneplain like that under discussion seems without parallel in present conditions. (2) The conditions round the base of Aspen Mountain are thought to indicate a moist climate at the time of planation. Those conditions are indicated by the accompanying sketch, Fig. 7. At the time of its development the peneplain extended with gentle slope close up to the base of the mountain. Later, under conditions of undoubted aridity, a mantle of piedmont gravels accumulated round the base of the mountain. Since the arid climate brought about the formation of the wash-apron it would seem that at the time of planation the climate must have been moister, for material resulting from weathering was then removed and the peneplain developed close up to the hard rocks of the mountain.

The basis of the assignment of the accumulation of piedmont gravels to an arid climate is this—under such conditions whatever rainfall there is usually comes in the form of torrents or cloudbursts. These give a very heavy precipitation over local areas for a short time, with resulting temporary streams of great transporting power. These occasional torrential rains act on slopes unprotected by vegetation and consequently pick up and carry forward a heavy load of rock-waste. Just as soon as the streams leave the steeper slopes much of this débris must be dropped, and all must come to rest within a comparatively short distance, for the water either sinks into the ground or rapidly evaporates. The consequence of this process is the accumulation of piedmont gravel slopes round the higher lands. Under a moist climate the streams are permanent, they work continuously; the slopes are protected by vegetation, hence furnish less débris to the waters of a passing storm. Weathering reduces the rocks to finer particles, which are exported by the ever-flowing streams, consequently degradation rather than aggradation is the rule. It is believed that under these conditions planation, with the removal of the resulting waste, would be pushed close up to the base of the harder rocks.

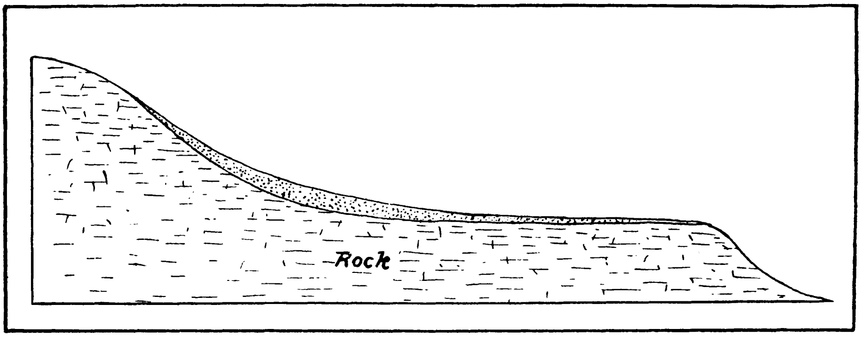

FIG. 7.—Sketch showing conditions round the base of Aspen Mountain. A lens-shaped débris fan mantles the lower slopes.

This, as an explanation of the conditions round Aspen Mountain, is not without its uncertainties, for it might be argued that conditions of extreme aridity might allow the development of a flat or gently sloping plain close up to the base of the mountain by wind erosion. In that case the efficiency of the wind in removing loose débris from round the base of the mountain must have been greater than that of the temporary streams in loosening and carrying material down the slopes, for any such piedmont dĕbris must be removed before the wind can attack the rocks at the mountain-base. In an absolutely rainless region there would be no difficulty in accepting this explanation, but there seems to be no region which is without its occasional rains, and a slight amount of rainfall distributed as it is in the deserts in the form of local torrents would be sufficient to bring down a considerable quantity of dĕbris from the bare slopes of the mountain—more it would seem than could be effectively disposed of by the wind.

From the foregoing lines of reasoning it is thought that the planation was the result of long-continued subaërial denudation under conditions of a moist climate. This belief is not held with great confidence, however, for it is recognized that desert erosion might under certain conditions produce similar results.

The surface of the gravels, from Miller Mountain northward to near the low area, slopes to the north at the rate of between seventy and one hundred feet per mile. The underlying rock-surface has a slightly lower slope. Judging from the present slope and attitude of the gravel-deposits it seems unlikely that there has been any considerable change in slope of the underlying peneplained surface since they were laid down, though there may have been a general elevation of the whole region. The gravel surface is a graded slope and shows no sign of disturbance since its formation. The transportation of large bowlders such as those on Miller Mountain would require a considerable gradient, probably as great as that at present. On the other hand, the development of a peneplained surface as even as that under discussion would require a more nearly horizontal attitude than at present at the time of planation, at any rate if this were accomplished under conditions of a moist climate, as there seems reason to think was the case. Whether or not such a surface with such a slope could be formed under desert conditions by wind scour is more difficult to determine, but it seems unlikely. The present slope would therefore indicate that, unless planation was the result of wind erosion, this portion of the peneplain when formed was more nearly horizontal than now and that it was tilted toward the north at a time of renewed uplift of the Uintas immediately antedating the deposition of the gravels.

Cause of the invasion of the gravels.—The gravels which form the capping of the peneplain were, in the southern part of the area, unquestionably derived from the Uintas. During the long period of quiet while the peneplain was developing, any considerable elevations in the Uintas must have been considerably reduced and very possibly planed off to correspond with the character of the adjoining country. At any rate they were not then supplying débris to the adjacent low-lying areas.

In order to bring about the change from these conditions to those which followed, in which great desert fans spread out from the mountains and covered the adjacent plains to distances of from thirty to forty miles or more, there must have been a decided change in the relations of plains and mountains. A change of conditions capable of producing so great results could have been no less than a pronounced renewed uplift of the Uinta mountain-range with the consequent development of extensive débris fans.

As a test of the preceding, let us postulate conditions as they seem to have been at the end of the period of planation, with the whole country, including the Uintas, reduced to low relief and lying at a comparatively low altitude. What then would be the effect of a marked uplift of the mountain-range?

In the first place there would, in all probability, be a marked change in climate. The high mountain-range to the south would cut off some of the moisture-bearing winds; with the result that the adjacent lowlands would become more arid. This effect would be increased if at the same time the Wasatch range, which runs north and south about one hundred miles west of this area, were also elevated so as to cut off the winds from the west. The high lands of the Uintas, attacked by the agencies of denudation and receiving most of the precipitation, would supply to the streams large quantities of rock-waste which, on account of the arid nature of the climate, could not be entirely removed to the sea, but would accumulate at the base of the range in the form of alluvial fans such as are developing at the base of the desert-ranges today. These fans as they grew would gradually spread out over the peneplain to the north, burying first the region close to the base of the mountains and later that farther away. In the meantime these more distant parts would be exposed to the agencies of an arid climate until the fans finally reached them. We should expect to find then along this outer zone not a deep residual soil formed during the time of planation, but fresh rock floors resulting from exposure to an arid climate before the fans reached so far out.

The effect of an arid climate on a monadnock like Aspen Mountain should be apparent in the mantling of the slopes with débris. This, owing to the lack of a protective covering of vegetation on the slopes, would be comparatively rapidly carried down by the desert torrents and accumulated at the base as has already been suggested. This is the actual condition at the base of Aspen. Starting at the low area and going toward the mountain one finds that the gravel-deposit is all of local nature and gradually thickens till, near the base of the mountain, it has an observed thickness of over two hundred feet and the base was not seen. It thins again as it laps up on the sides of the mountain. The section radially to the mountain is lenticular in form, the bottom corresponding to the rock-slope of Aspen as developed during the time of planation, and the top being graded to the slope of the desert fans, which is considerably more gentle.

The bed-rock in the low area is fresh, as already stated; a condition which agrees equally well with the succession of events just postulated, as with the idea of planation under desert conditions.

The relation of the Miller Mountain gravels to the Uintas corresponds in all respects with what we should expect in the case of gravel fans accumulating at the base of high mountains in an arid climate, not only in the nature of the material in the fans, but also in the distribution and general attitude of the deposits.

Reasoning thus we are led to the conclusion that the period of planation was brought to a close by a renewal of mountain uplift during which the Uintas were greatly elevated with respect to the surrounding plains; that this period of mountain-making was probably followed in this region by a change from a comparatively moist to an arid climate; and that great desert fans of gravel and sand spread out from the mountains far over the plains, while at the same time smaller fans spread out in like manner from the monadnocks of the plains and merged with the gravels from the mountains.

It seems likely that this mountain uplift was accompanied by tilting of the land for twenty miles or so north of the mountains, for, as stated already, the rock-surface over this area slopes toward the north at the rate of about seventy-five feet per mile; a slope which seems too great to have remained undissected under the conditions of planation.

The Uintas at the time of the deposition of the gravels rose to a much greater height than at present, for to the south of Little Mountain and Miller Mountain the present summits of the range are little if any higher than the base of the gravels on these plateaus. The highest summit north of Green River is about 8,250 feet, while the summit of the plateau at Miller Mountain is 8,500 feet and Little Mountain is still higher. South of the river the mountains are somewhat higher, but even here they are only fron 300 to 1,000 feet above the tops of the gravel-capped plateaus. This in a distance of from fifteen to twenty-five miles gives a slope entirely inadequate for the transportation of the coarse gravel found on Miller Mountain. If the present grade of the gravel surface on Miller Mountain, one hundred feet per mile, were prolonged for fifteen miles it would amount to a rise of 1,500 feet. This is not enough, for the fans were necessarily steeper near the mountains than farther out so that at the very least the mountains must have been 2,000 feet higher than now to give sufficient grade to account for the transportation of the gravels to their present position, and this is not taking into account the still greater elevation necessary to furnish a supply ground for the material of the fân.

The course of Green River during this time of mountain-building cannot be discussed here, as its relation to the gravels close to the base of the mountains is not known to the writer. At present it flows between the gravel-deposits of Miller and Little mountains and the higher parts of the Uintas from which the gravels were derived. We are led then to one of two alternatives: either the river was not flowing in its present course at the time the gravels were deposited, or the gravels were derived entirely from the part of the mountains north of the river. Further observations will be necessary to determine this point. It is suggested that a study of the relations of the river and gravels in and near the mountains is likely to furnish valuable clues toward the solution of the problem of the history of Green River and its relation to the Uinta Mountain uplift.

In connection with the evidence of the uplift of the Uintas at or near the close of the Miocene it is a significant fact that the lava-flows of the Leucite Hills were spread out on the surface of this Tertiary peneplain. Earth movements of great magnitude such as those responsible for the uplift of the Uintas are likely to be accompanied by volcanic activity, either in the area of uplift or in neighboring regions. With this fact in mind it would seem more than a coincidence that the Leucite Hills lavas were extruded at about the time of the building of the outwash gravel fans from the newly uplifted Uinta Mountains; since both fans and lava-flows lie on the undissected surface of the peneplain. In this connection it is interesting to note that in the Sierra Madre about one hundred miles to the east Ball[1] has found high-level gravels similar to those of the Rock Springs region, in some places overlain by lava-flows.

Studies in the West[2] have shown that the close of the Miocene or more probably the transition period between the Miocene and the Pliocene was a time of extensive mountain uplifts and crustal movements. The Tertiary peneplain of the Colorado valley was, according to Dutton,[3] uplifted at this time. Large parts of the Great Basin and the Sierra Nevada and Cascade mountains were elevated. It was at this time that the topographic features of the West began to take shape somewhat as they are today. There occurred over the whole Cordilleras a regional uplift as well as one of individual mountain-ranges. Coincident with these crustal movements were the great lava-extrusions of the late Miocene.

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[1] Max W. Ball, "The Eastern Part of the Little Snake River Coal Field, Wyoming," *U.S.G.S. Bull. 381*.

[2] See Chamberlin and Salisbury, *Text Book of Geology*, III, 274–75, for references.

[3] Dutton, *Monograph II*, U.S. Geol. Survey.

The fact that the succession of events indicated by the gravel-covered peneplain with its associated features, as worked out independently of these other studies, agrees so closely with their results, strengthens the conclusions reached as a result of our local investigation.

PHYSIOGRAPHIC CHANGES SUBSEQUENT TO THE GRAVEL-DEPOSITION

1. *Erosion.*—Practically all the erosion which gives rise to the present diverse topography of the Rock Springs region is subsequent to the deposition of the gravels. Over wide areas these are entirely removed, and wherever present they are merely remnants standing, in general, over 1,000 feet above the major stream-valleys. The present streams, which over the area once covered by the gravels must have been initiated on the gravel surface, are superposed discordantly on the underlying rocks. The minor tributaries are subsequent on the structure, while the major streams are entirely independent of it. In one instance, that of Salt Wells Creek, the stream three times breaks across a scarp over 1,000 feet in height. Wide areas in the softer rocks have been reduced to low relief at elevations from 800 to 1,000 feet below the old peneplain level. Except where protected by lava-flows or the gravels, even the tops of the scarps of harder sandstone are several hundred feet below the peneplain level. All of this erosion has taken place since the deposition of the gravels.

Present denudation is being accomplished by wind and water together. The hardness and position of the rocks are the determining factors in the rate of erosion. In general the harder rocks stand out in the form of scarps. Horizontal rocks have shown greater resistance than the same rocks in an inclined position.

As already pointed out, the Uinta Mountains from which the gravels were derived are now lower than the tops of the gravel-deposits fifteen miles and more away and are separated from them by a valley at least 2,500 feet deep (see photograph, Fig. 8). They must therefore have been subjected either to profound denudation since the gravels were spread out over them, or to downthrow by faulting. If their present low elevation is due to denudation this must have been relatively much greater than that of the gravel-capped plateaus. This is not unreasonable, for one would expect that denudation would be more effective in the mountains, exposed as they are to the excessive action of frost and wind, with steep slopes and highly inclined rocks, than in an adjacent lower region of nearly horizontal rocks, even though the rocks in the mountains are harder. Then too, in the case of the Uintas, Green River flows through them in a deep canyon. This gives steep slopes and consequently more rapid erosion of the adjacent mountains than of the plateaus farther away. As to the alternative of a downthrow of the mountain-block since the gravels were deposited, there is some uncertainty. The principal uplift of the northern flank of the Uintas took place along a fault whose maximum displacement amounted to over 25,000 feet, but there seems to have been a certain amount of downthrow as well as uplift along this fault-zone. Powell[1] described such a downthrow running in an east-and-west direction south and southeast of our area, which he believed had lowered the mountain-block by from 1,000 to 3,000 feet in various

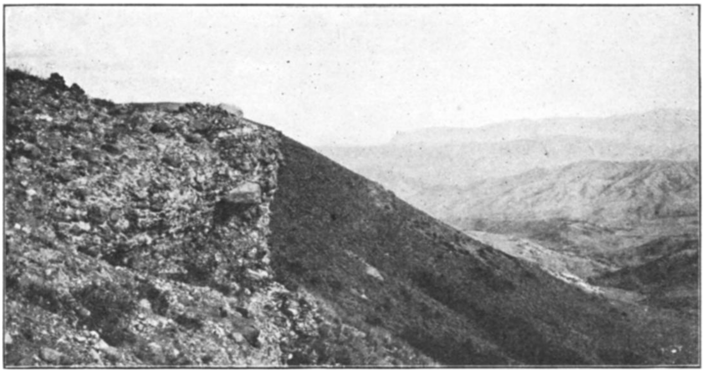

FIG. 8.—A typical exposure of the conglomerate on the south face of Little Mountain. This is a view looking southeast into Red Creek basin; the bottom of which lies some 2,500 feet below. The outlying ranges of the Uintas may be seen in the background to the right. Red Creek valley lies between the plateau and the mountains. This view gives some idea of the character and immense amount of erosion which has been accomplished since the conglomerate was laid down. (Photo. by A. R. Schultz.)

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[1] Powell, *Geology of the Uinta Mountains*, 204–6.

places along the fault-line. This fault is described as displacing beds of the Brown's Park Tertiary, but since these beds have been considered to be of earlier age than the Bishop Conglomerate, there is no evidence to indicate the exact time of the displacement; whether before or after the development of the conglomerates.

It is therefore impossible to determine from the data at hand whether the present low elevation of the eastern end of the Uintas, relative to the gravel plateaus, is the result of down-faulting or of simple denudation, with a more rapid lowering of the tilted rocks close to the deep canyon of Green River than of the gently sloping gravel-capped plateaus farther away. Whatever may be the final decision of this point, there can be no question as to the profound denudation subsequent to the gravel-deposition. Red Creek basin, over 2,500 feet deep, and lying outside of the faulted zone, gives a fair measure of this denudation.

The period of erosion continued until all the valleys of the region were deeper than they are at present, though just how much deeper is not known. This erosion evidently took place under conditions of a moderately moist climate, for great amounts of material have been removed by the rivers. A desert climate favors accumulation rather than removal.

2. *First period of aggradation.*—After this period of degradation there came one of aggradation, during which the valleys were partly filled by deposits of silt and gravel washed down from the valley-sides. On the west side of Salt Wells Creek, along and south of Pretty Water Creek, there is an extensive wash-apron derived from the high, gravel-capped Miller Mountain plateau. This wash-apron mantles the slopes down to the valley-bottom, where it grades into a flat-topped valley-filling which now remains as a distinct terrace about forty feet above the present stream (Fig. 9). This valley-filling must have had a depth of considerably over forty feet, for bed-rock is nowhere exposed in the stream-bottom. At least one hundred feet is thought to be a moderate estimate. There are no wells to indicate its exact depth.

This period of aggradation is referred to a change to a more arid climate than that under which the major erosion was accomplished. Under arid conditions the occasional torrential rains, acting on slopes unprotected by vegetation, loosen and bring down heavy loads of dêbris, which the streams, on account of their intermittent character and the rapid dissipation of the water after a shower by evaporation and absorption into the dry soil, are unable to carry out of the valleys. The result is the silting up of the valleys and the formation of alluvial fans and wash-aprons on the slopes. On the return to a moister climate the streams become permanent, the land is protected by vegetation, hence furnishes less dêbris to the waters of a passing storm, with the result that the wash-aprons and silted valleys built up under arid conditions are dissected, leaving gravel terraces along the stream courses.

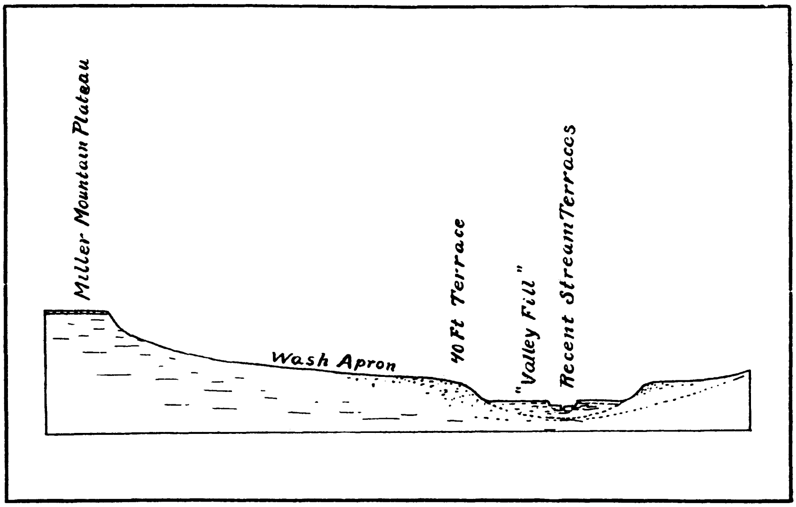

FIG. 9.—Sketch showing conditions along Salt Wells Creek. This sketch shows all the terraces referred to in the text, and their relations to each other and to the Miller Mountain plateau. Vertical scale exaggerated.

3. *Erosion.*—Following the preceding stage of desiccation and aggradation there came one of erosion when the wash-aprons were dissected by the streams and the gravel and silt deposited in the central part of the valley were cut down, leaving remnants as flat-topped terraces on either side. This feature is best shown along Salt Wells Creek from the junction of Pretty Water Creek to Chimney Rock, about two and one-half miles to the north. There a cut from one-fourth to one-half mile wide has been made through

the silts and gravels. The resulting terrace is from twenty to forty feet in height and is clearly marked. At the point where the wash-apron feature is best developed, south of Pretty Water Creek, the minor topography is entirely subsequent to the wash-apron, which forms partly dissected, flat divides between the streams. This period of erosion and dissection of the gravels is referred to a cessation of the arid conditions and a return to a moister climate.

4. *Second period of aggradation.*—The full extent of the dissection of the preceding period cannot be seen, for a second period of aggradation has followed and the bottoms of the stream-valleys have again been silted up to an unknown depth. This is the "valley-fill" of the present streams. All the streams, large and small, of the Rock Springs region have this filling which varies, according to the size of the stream, from a few feet to more than a mile in width. The material of this "valley-fill" is a sandy loam with many of the characteristics of loess. It stands up in vertical cliffs along the stream-trenches, sometimes to a height of twenty feet.

The aggradation responsible for this valley-fill is thought to be due without question to a change to more arid climatic conditions. In one of the narrow valleys cut through the high sandstone scarp west of Salt Wells Creek the filling progressed until the bottom of the valley was changed from a graded stream-bed to a series of fans which entirely destroy the grade along the valley-bottom. It is plain that such an effect could be produced only in an arid climate. In this case the valley was small and evidently, during the arid period, could not support even a temporary stream.

5. *Present period of slight dissection.*—In the case of the valley just described the stream is at present cutting through the fans and has almost succeeded in bringing its bed down to grade again. The stream now flows only in times of flood, so that this action is not rapid. All the streams of the region are beginning the dissection of the "valley-fill." Along the larger ones a series of distinct terraces is forming (see Fig. 10). These are migrating up stream. Three terraces in the lower course of a stream give place to two higher up and to a single trench still higher. In several places the mode of retreat was noted. It is by a fall from one or two to five

or six feet in height. All things point toward the conclusion that this dissection is still in progress.

A slight increase in precipitation is thought to be the cause of the dissection. What but a change in the amount of rainfall would account for the building of desert fans across a small stream-valley and their subsequent dissection by the stream?

Confirmative evidence of recent increased precipitation is furnished by a belt of sand dunes about forty miles north of Rock Springs. This belt of dunes begins in the broad plain of the valley of Big Sandy Creek near its junction with Green River, and extends eastward through a low gap in the scarp west of the Leucite Hills, between two of the larger of these, Steamboat and North Table, and thence eastward across the plain of the Red Desert for many miles. The belt of dune sand varies from one or two to five miles in width. All along the dune strip the vegetation is encroaching on the dunes. In crossing from one side to the other, one passes first an area from one-fourth to one-half mile in width of stagnant, sage-covered dunes, then a belt of active dunes with almost no vegetation, and finally on the other side another belt of sage-covered dunes. West of the pass, on the plains of the Green River valley, the strip of active dunes rapidly narrows to a wedge which pinches out about four miles west of the pass. Here, and farther

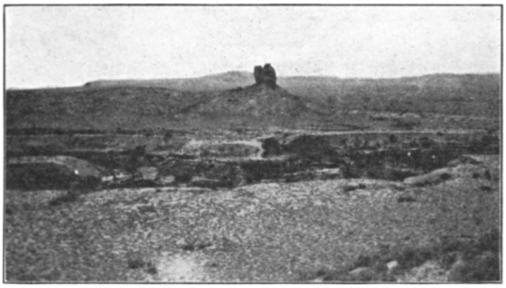

FIG. 10.—Looking across Salt Wells Creek toward Chimney Rock, showing the flat "valley-fill" in which the stream is developing a series of terraces. Three distinct terraces are found at this point. The view gives a good idea of the general character of the flats formed during the latest period of aggradation. Chimney Rock is nearly one-half mile distant, and the flat is here over one-quarter mile in width. (Photo. by B. L. Johnson.)

west as far as one can see, there is still the dune strip three or four miles wide, but all is covered with vegetation. The irregular dune topography still remains and in places is as well developed as in the area of actively moving sand. Sage brush, often as high as a man's head, covers the dunes.

It is evident that at the time these dunes were forming, the climatic conditions must have been different than at present. A change, either to greater precipitation or lowered mean temperature, or both, with consequent lessened evaporation, would allow vegetation to gain a foothold on the dunes.

This, taken in connection with the fact that the streams are now dissecting the valley-filling formed during a previous dry period, is strong evidence of recent increased precipitation, or, what amounts to the same thing, a cooler climate with lessened evaporation.

It might perhaps be argued that the series of terraces found along the streams could be due to changes in level of the land rather than to changes in climatic conditions. To account for the terraces on this basis would necessitate the following series of crustal movements: First, elevation during the first great erosion; second, depression to account for the first period of aggradation; third, elevation to account for the second period of erosion below the bottoms of the present streams; fourth, depression to account for the second period of aggradation and the formation of the "valley-fill"; and fifth, another slight elevation giving rise to the present stream-trenching. Such an explanation necessitates too many unproved crustal movements.

Relative lengths of the periods of terrace-formation.—It must not be supposed that all these different periods of aggradation and dissection were of equal duration or importance. By far the most important event since the deposition of the high-level gravels was the long cycle of erosion which produced the dominant features of the present topography. All the later terraces are minor features developed within the larger valleys resulting from this great erosion, and represent comparatively recent climatic fluctuations. Fluctuations of equal or greater magnitude might have occurred while the great erosion was in progress without leaving any surviving record.

Comparison of other observations bearing on the problems presented in this paper.—Both King[1] and Powell[2] described the high-level gravels of this region—King, under the name of Wyoming Conglomerate, and Powell under that of Bishop Mountain Conglomerate. Powell recognized the true nature of the gravels as well as the peneplained surface on which they lie. He writes:

> The Bishop Mountain Conglomerate is found at different places to lie unconformably upon every group of the table which is represented in the Uinta Mountains and adjacent country. Its plane of demarkation represents a cessation of the movements of displacement in the region over which it is found, and that the same region was planed down to a base-level of erosion, which base-level was continued during the accumulation of these beds, for it is believed to be a subaërial conglomerate; but should further evidence prove it to be a subaqueous accumulation the plane of separation would then represent an epoch of change from a period of erosion to a period of deposition.[3]

As to the mode of accumulation he has this to say:

> I think that many geologists would ascribe this conglomerate to the action of ice, but throughout all that portion of the Rocky Mountain region which I have studied, I have so frequently found gravels and conglomerates of subaërial origin, and have in so many cases found reason to change my opinion concerning them, often having attributed a driftlike deposit to glacial action, and afterward, on further study, abandoned the theory, being able to demonstrate its subaërial origin, and witnessing on every hand the accumulation of such gravels in valleys and over plains where mountains rise to higher altitudes on either side, and having in so many cases actually seen the cliffs breaking down and the gravels rolling out on the floods of a storm, I am not willing to disregard explanations so obvious and so certain for an extraordinary and more violent hypothesis.[4]

Hayden in connection with his "Survey of the Territories"[5] reports high-level gravel-deposits similar to those of Miller Mountain as occurring on Table Mountain, an isolated butte southeast of the Wind River range; in the valley of South Pass; and along the

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[1] Clarence King, *Explorations of the 40th Parallel.*

[2] J. W. Powell, *Geology of the Uinta Mountains*, U.S. Geol. and Geog. Survey, Division II.

[3] J. W. Powell, *Geology of the Uinta Mountains*, 62.

[4] *Ibid.*, 170.

[5] Hayden, *U.S. Geol. and Geog. Survey of the Territories of Idaho and Wyoming, 1877*, 133.

Seminole Mountains. Darton[1] describes flat-topped deposits of coarse conglomerate capping some of the higher divides of the Bighorn Mountains of Wyoming. As already stated, Woodruff[2] finds similar gravels in the Wind River basin, and Ball along the flanks of the Sierra Madre. It is highly probable that further work will demonstrate that all these deposits are genetically related and are the results of the same set of widespread physical conditions.

The later stream-terraces developed in the valleys of the Rock Springs region are thought to be susceptible of correlation with the fluctuations in size of the lakes of the Great Basin, particularly of Lake Bonneville as worked out by Gilbert.[3] Gilbert's succession follows:

1. Pre-Bonneville low-water epoch. This was of long duration.
2. First epoch of high water.
3. Interval of low water, probably with complete desiccation.
4. Second epoch of high water. This was only about one-fifth as long as the first of the high-water epochs.
5. Post-Bonneville epoch of low water, continuing until recent times.

When the succession worked out from the Rock Springs stream-terraces is compared with this it is found that, beginning with the present and working backward, the long period of erosion following the deposition of the high-level gravels on the plateau includes Gilbert's first epoch of high water. From that to the present the two agree closely, the periods of aggradation corresponding to the epochs of desiccation of the lakes, and periods of erosion corresponding with the epochs of high water.

It is believed that, as in the case of the Great Basin lakes, the climatic changes recorded by the stream-terraces are to be correlated with those of the Pleistocene glacial epochs. No glaciers invaded any part of the drainage-area of the Rock Springs region, consequently *the evidence furnished by stream-terraces is entirely free from complications arising from the presence of outwash glacial gravels.*

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[1] N. H. Darton, *U.S. Geol. Survey, Professional Paper No. 51*, 67–70.

[2] *Loc. cit.*

[3] G. K. Gilbert, "Lake Bonneville," *U.S. Geol. Survey, Monograph 1.*

SUMMARY

The succession of events indicated by this study is as follows:

1. *Planation*, in progress during the latter part of the Tertiary, reduced the Rock Springs region, including all the area from the Uinta Mountains to the northern end of the Leucite Hills, to the condition of a peneplain of very even surface surmounted by a few small monadnocks of especially resistant rocks. This peneplain is possibly to be correlated with that of the high plateau country to the south in Utah and Arizona.

2. *Mountain-building.*—Pronounced orogenic movements in the late Miocene or early Pliocene brought the foregoing period of planation to a close. These movements resulted in a very considerable renewed uplift along the Uinta mountain-range and a general elevation of the whole region. A change to a more arid climate than formerly is also indicated. Extensive waste slopes or desert alluvial fans were developed round the base of the mountains, and spread far out over the adjacent plains. A remnant of this desert-fan deposit forms the Bishop Conglomerate described in this paper.

3. *Erosion.*—A long period of erosion, probably with a moderately moist climate and relatively steep stream-grades, gave rise to the present diverse topography. Subsequent to the deposition of the gravels, erosion or faulting reduced the height of the Uintas so much that parts of the mountains which must have supplied the gravels now lie at levels lower than the tops of the gravel-beds fifteen to twenty miles away.

4. *Aggradation.*—A change to arid climate brought about a cessation of erosion and a change to conditions of aggradation. The stream-valleys were silted up, and extensive wash-aprons developed at the base of the steeper slopes.

5. *Erosion.*—A return to moister climate resulted in the partial dissection of these wash-aprons and valley-gravels, producing terraces along the valley-sides.

6. *Aggradation.*—Another change to aridity resulted in the formation of the "valley-fill" of the present streams. Some smaller stream-valleys with steep side slopes were partially choked and the stream-grade destroyed by desert fans.

7. *Erosion.*—A recent slight increase in precipitation is indicated by the renewed cutting by the streams and by encroachment of vegetation on the sand dunes.

Conclusion.—In conclusion it is suggested that future correlations of the high-level conglomerates, as well as of the later terraces in the stream-valleys, can be most satisfactorily made on a genetic basis. It will, in most cases, be impossible to trace these features from one drainage-system to another directly. The only basis for comparison is that, in general, like conditions will produce like results, and if the conditions affect large areas, as for instance climatic changes or great periods of planation or mountain-building, their results will be equally widespread.